A Novel Capacitive Detection Principle for Coriolis Mass Flow Sensors Enabling Range/Sensitivity Tuning

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Summary We report on a novel capacitive detection principle for Coriolis mass flow sensors which allows for one order of magnitude increased sensitivity. The detection principle consists of two pairs of comb-structures: one pair produces two signals with a phase shift directly dependent on the mass flow, the other pair is used to cancel the actuation signal. This results in larger phase shifts for the same mass flows. The range and sensitivity of the sensor can be tuned by changing the amount of cancellation of the actuation frequency, e.g. the size ratio between the comb-pairs.

Background A Coriolis mass flow sensor consist of a vibrating tube. Therefore, a fluid flowing inside the tube is subject to Coriolis forces, which actuates a different mode shape with an amplitude dependent on the mass flow. This transduction principle is independent of pressure, flow profile or temperature [1]. Figure 1a illustrates the twist mode (due to actuation) and the swing mode (due to the Coriolis force).

The micromachined Coriolis sensor from Haneveld et al. has two comb-structures at the tube for capacitive readout. The swing mode introduces a phase shift between the two capacitances as is illustrated in Figure 1b. The sensitivity of the flow measurement is restricted by the sensitivity of the phase measurement electronics; we propose a novel readout principle that increases the phase shift for the same mass flows. Highly sensitive mass flow sensors are interesting for systems that need very accurate flow control, e.g. intravenous therapy and the chip industry.

Theory The sensor consists of a □-shaped tube with large and small comb-structures on both sides as is sketched in Figure 1c. Both large combs have a capacitance that is equal to the sum of the actuation signal ($C_{\text{act}} \sin(\omega t)$) and the Coriolis signal ($C_{\text{cor}} \cdot \cos(\omega t)$). Using trigonometric identities, this sum can be rewritten to a single sine function as described in the following equation:

$$C_{\text{act}} \sin(\omega t) + C_{\text{cor}} \cdot \cos(\omega t) = C_{cmb} \sin(\omega t + \phi),$$

as long as the following relation holds: $C_{\text{cor}}/C_{\text{act}} = \tan(\phi)$, with $C_{\text{act|cor|cmb}}$ the amplitude, ω the frequency, t the time and ϕ the phase shift. Latter equation can be rewritten to: $\phi = \arctan(C_{\text{cor}}/C_{\text{act}})$. Reducing C_{act} can be achieved by cancelling the actuation signal component by adding its negative variant, produced by the small combs. This leads to a higher $C_{\text{cor}}/C_{\text{act}}$-ratio and therefore results in a larger phase shift.

Fabrication is done using surface channel technology [1]. A photo of the device is shown in Figure 2 and a SEM close-up is shown in Figure 3.

Result Measurement results for mass flows (water) from $0\,\text{g}\,\text{h}^{-1}$ to $5\,\text{g}\,\text{h}^{-1}$ without and with attenuated actuation frequency cancellation are shown in Figure 4. Figure 5 shows the result when the actuation signal is maximally cancelled. Future work will focus on the integration of multiple connectable series capacitors for the small combs, to tune the cancellation. This makes post-fabrication tuning possible, which helps to tune the sensor in a way that its range is in the linear part of the arctan-curve.

References

[1] J. Haneveld, et al. Modeling, design, fabrication and characterization of a micro Coriolis mass flow sensor, J. Micromech. Microeng., vol. 20, nr. 12: p. 125001, 2010.

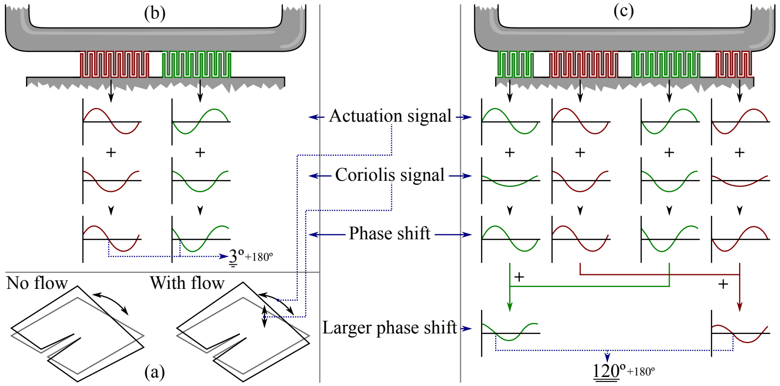

Figure 1: A Coriolis mass flow sensor is actuated in twist mode, the Coriolis force due to a flow causes the swing mode (a). Conventional capacitive read out provides a phase shift between the two combs (b). The novel read out cancels the twist mode partly, therefore, the phase shift is larger allowing for higher sensitivity.

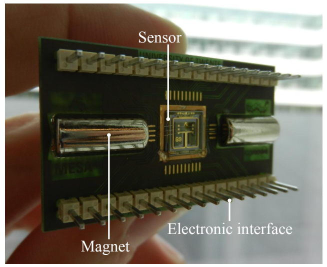

Figure 2: Assembled sensor on PCB with magnets and electronic interface. The fluid inlet is on the other side of the PCB.

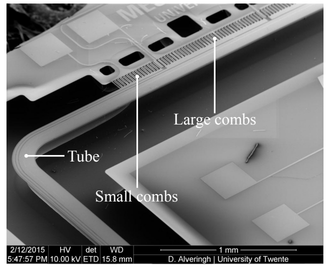

Figure 3: SEM close up of the tube with the large and small comb-structures at one side of the tube.

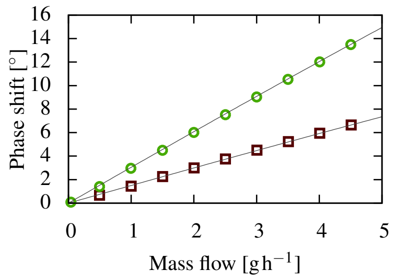

Figure 4: Conventional readout (□) and novel readout (○) measurement results using attenuated actuation signal cancellation. Arctan fit.

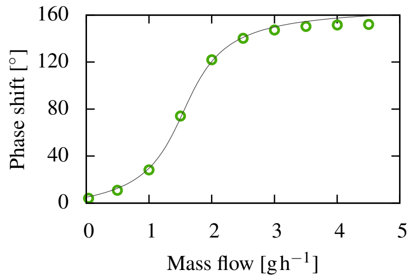

Figure 5: Novel readout measurement results, using maximum actuation signal cancellation (○). Arctan fit.